Solar System Surveys

by

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1. Introduction

Astronomical data is a necessary starting point for a virtual observatory. Solar system surveys sponsored by NASA's Near-Earth Objects (NEOs) program provide extensive sky coverage and vast amounts of celestial images. Their primary goal is the discovery and characterization of NEOs--asteroids and comets, but the data are applicable to many astrophysical studies. Below, we list and briefly describe the ongoing NEO programs. We also describe how the Near-Earth Asteroid Tracking (NEAT) program archives its data, making it available for the science community through the SkyMorph project, part of NASA's Applied Information Systems Research program (AISRP).

2. The Surveys

NASA intends to discover 90% of the Near-Earth asteroids larger than 1 km by 2010. At least 50% of these objects remain to be discovered (Rabinowitz et al. 2000, Nature, 403, 165). To fulfill this goal a number of observing groups use meter-class telescopes with electronic CCD cameras to perform large-scale surveys of the sky at least 18 nights each month. The surveys cover many 1000s of degrees of sky each month. The limiting magnitudes are in the range V=17-20. Thus millions of objects are observed. The projects are listed in Table 1.

Table 1.

Project	**Telescope (s)**	**Nightly Data (GB)**	**Archive/Access**
Catalina (UA)	0.4,0.7-m	8	None
LINEAR (MIT/LL)	1.0-m (2)	70	None
LONEOS (Lowell)	0.6-m	5	None
NEAT (NASA/JPL)	1.2-m (2)	25-100	Both
Spacewatch (UA)	0.9, 1.8-m	13	None

Table 1 also shows that the total image data obtained nightly is about 100 GB, but will rise to about 200 GB when the second NEAT telescope comes on line.

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NEAT (Pravdo et al. 1999, AJ, 117, 1616) is the only project that places its image data in an archive that is publicly- accessible. A separate AISRP project called "SkyMorph" enables the NEAT archive. NEO operational funds are too tight to support this activity. The other projects, except for LINEAR, save their data, but only on tapes that are currently inaccessible. They are moving toward archiving their data but it appears that, like NEAT, an alternate funding source is required.

3. SkyMorph

SkyMorph is an example of how a large and ongoing astronomical data set can be ingested into an archive in near-real time. This is a desirable, perhaps necessary, attribute for a virtual observatory. The existing SkyMorph archive is an asset for the astronomy community, used in purposes as diverse as discovering supernovae and refining asteroid orbits. These data cover the dimension of time in a way that is unique among large optical databases: most of the sky is re-observed with the same instrument on time scales from hours to months to years.

Up to 25 GB/night of data is transmitted from the AFRL 1.2-m telescope site at Maui to JPL. These data are then processed within days and placed in the archive. Figure 1 shows the system architecture. The archive can be accessed at the worldwide web address:

http://skys.gsfc.nasa.gov/skymorph/skymorph.html

Like a virtual telescope, it gives users the ability to observe the sky, either by time and/or position, or through its Moving Target Detection utility. The latter "follows" a moving object through the sky and gives views of it from the NEAT database or from other currently implemented databases. Other databases include the Digital Sky Surveys and Hubble Space Telescope, with more to come.

SkyMorph also contains an object database. Users can select objects that have been viewed multiple times and, for example, construct light curves. Further utilities are planned for the object database to allow correlations with interesting sources in other wavelength regimes.

4. SkyMorph Data and Uses

Figure 2 shows the observation centers for data in the SkyMorph archive. Much of the sky is covered multiple times with notable exceptions at low galactic latitudes and the southern sky.

The underlying purpose for the NEAT data is to discover NEOs. Thus SkyMorph shows many examples of these objects. Figure 3 shows the comet Hale-Bopp and Figure 4 shows the Near-Earth asteroid Toutatis. Toutatis is shown as an overlay of three NEAT images taken at different times, and assigned red, green, and blue colors. The three images are aligned so that non-moving star images add to a white result, while the moving asteroid images appear in red, green, and blue.

Figures 5 and 6 are examples of how outsiders used SkyMorph to add to our scientific knowledge. These images show the asteroid 1998 MQ moving relative to the fixed stars. A European user successfully searched for pre-discoveries of this asteroid and latter submitted his findings to the Minor Planet Center for inclusion in its databases.

The Near-Earth asteroid $1999AN_{10}$ caused a stir soon after its discovery in early 1999. Its poorly known orbit left open the possibility of an encounter with the Earth in 30 years. Fortunately, a pre-discovery of this object on the Palomar plates refined the orbit, eliminating the threat. Figure 7 shows this pre-discovery image obtained using the Moving Target Detection utility of SkyMorph.

Moving further out in distance, Figure 8 shows how astrometric solutions for SkyMorph objects can detect proper motion. GJ 1146 is a nearby star located about 20 parsecs from Earth. The positions extracted from the database describe the proper motion of the star, on order 1 arcsecond/year.

Leaving our galaxy, Figure 9 illustrates why the Supernova Cosmology Project (SCP) is using NEAT data to discover supernovae in nearby galaxies. During two nights of observations in February 1999, the SCP discovered 5 supernovae including the one shown in the figure, SN 1999am. In the next few years the SCP is expecting to discover hundreds more supernovae in a similar fashion.

Finally, the distant quasar 3C 273 was serendipitously observed many times with NEAT. Figure 10 shows the light curve of this object and illustrates the capability of NEAT to provide long observing baselines for many interesting sources.

5. Conclusions and Plans

Solar system surveys, at least at the current rate, are planned to continue for 10 years. This enormous database is a significant resource for any national or international virtual observatory. Plans should be made for its inclusion. The NEAT data via SkyMorph is expected to increase by a factor of between 3-9 in sky coverage, yielding more than a terrabyte/week. A small investment now can ensure that these data are available in the future, not only for the uses described above, but also for uses not yet envisioned.

Figure 1

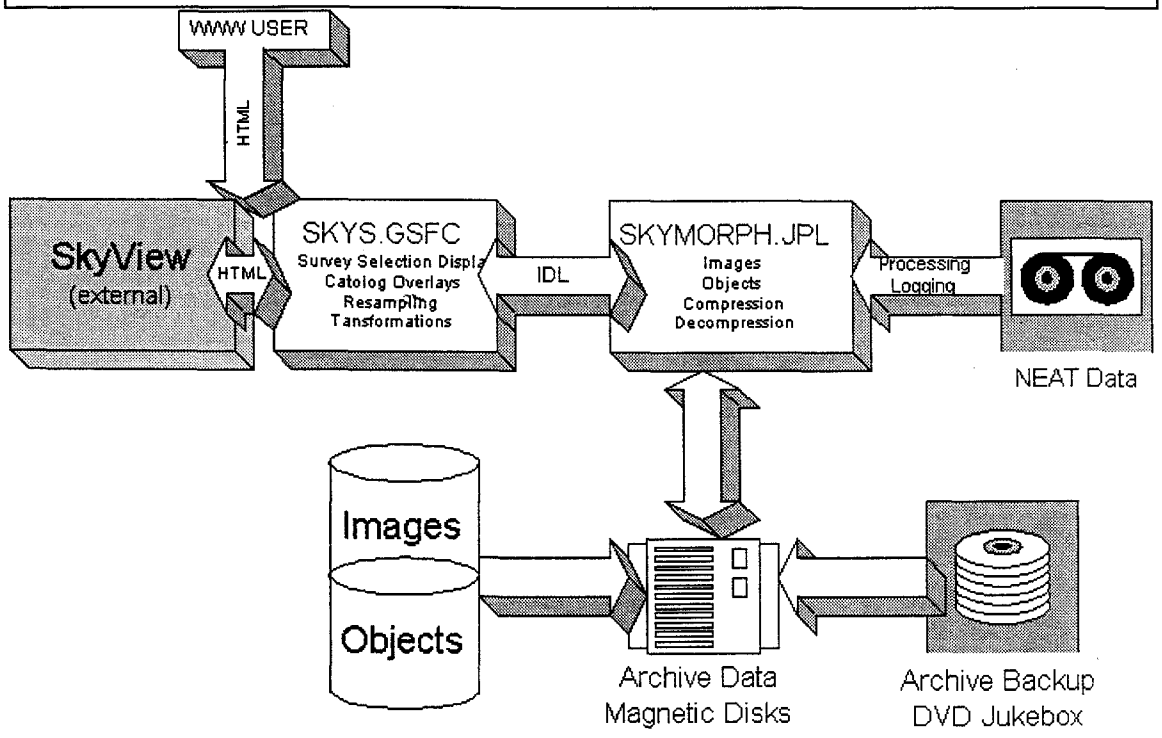

WWW USER
HTML
SkyView
(external)
HTML
SKYS.GSFC
Survey Selection Displa
Catalog Overlays
Resampling
Tansformations
IDL
SKYMORPH.JPL
Images
Objects
Compression
Decompression
Processing
Logging
NEAT Data
Images
Objects
Archive Data
Magnetic Disks
Archive Backup
DVD Jukebox

Figure 2

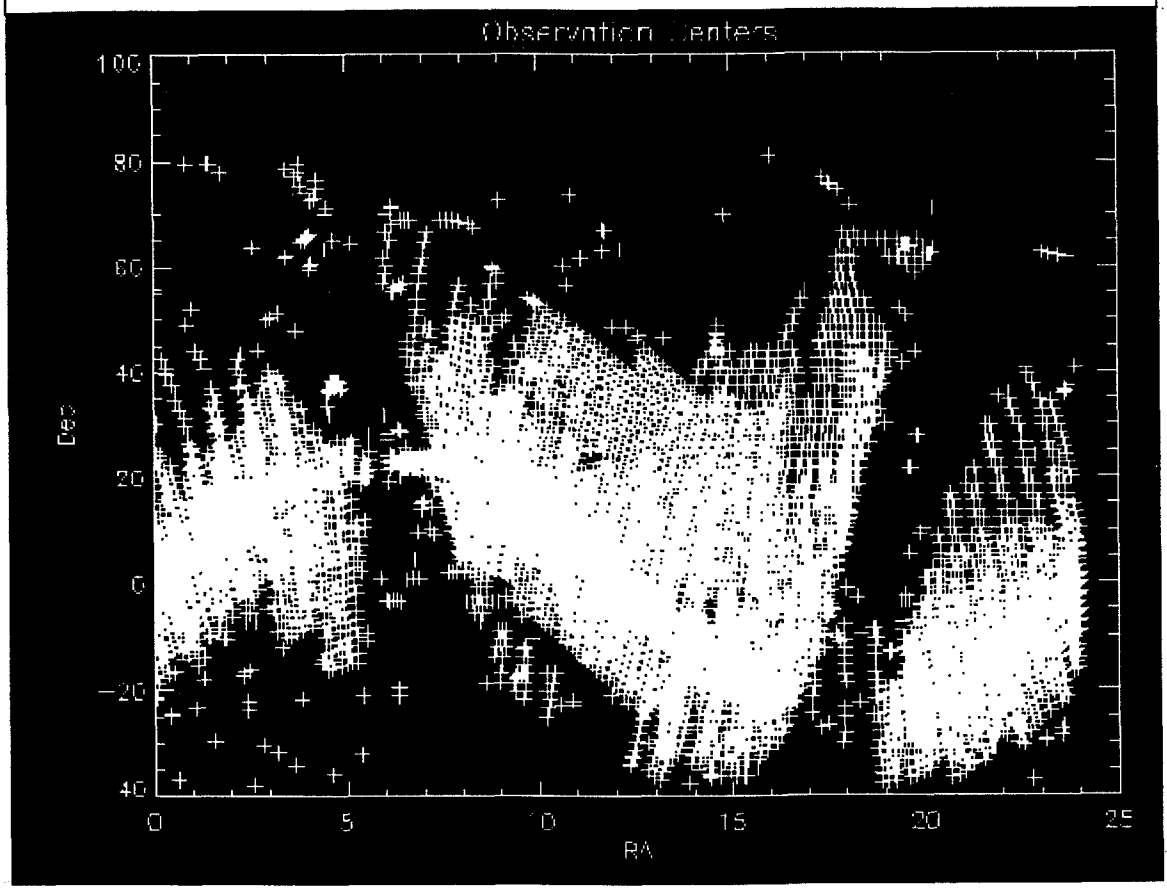


Figure 3

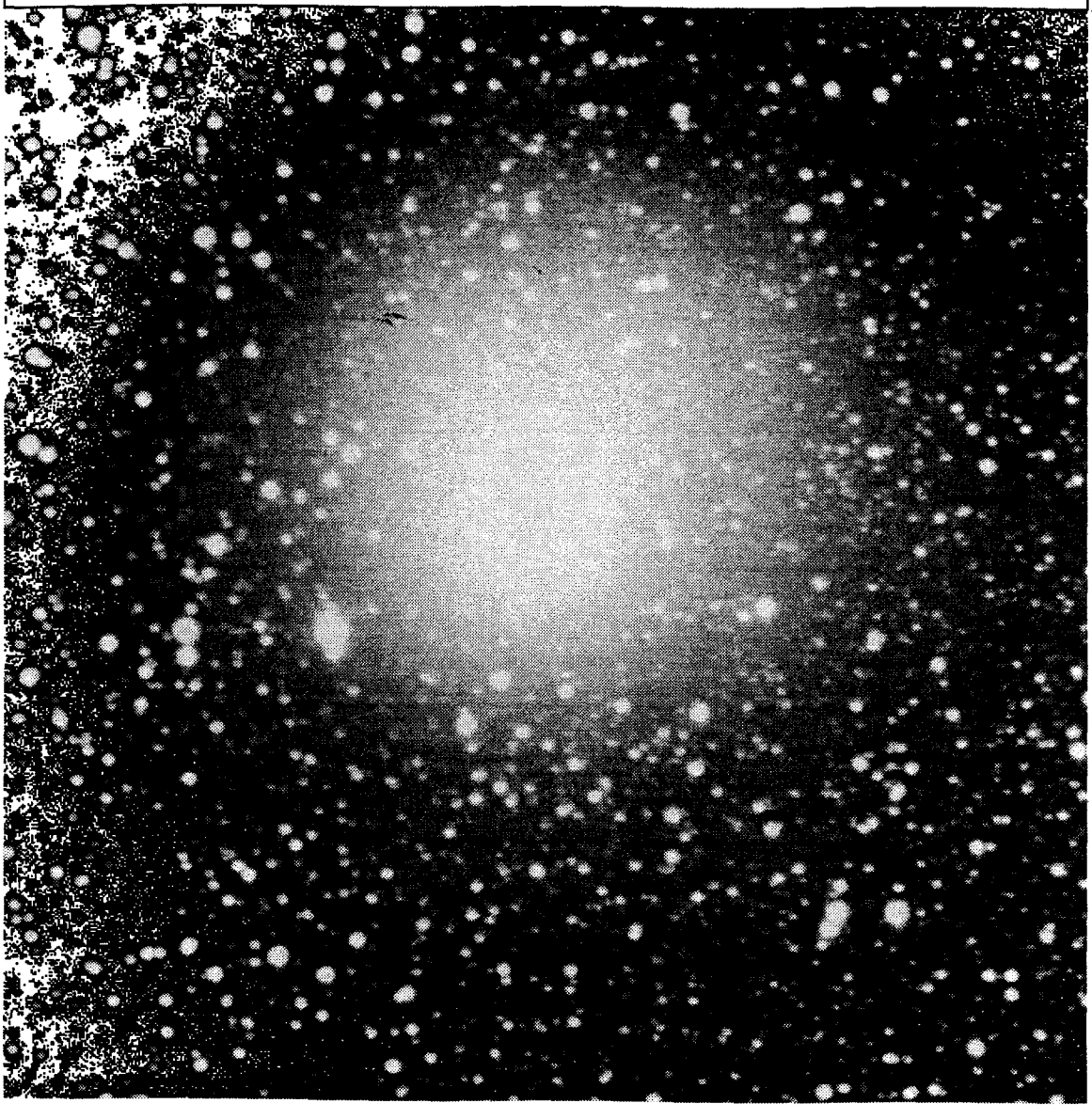


Figure 4

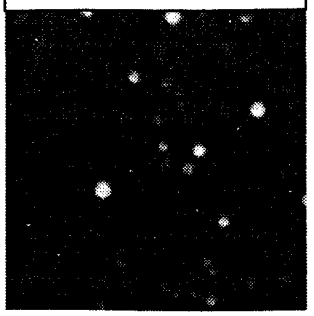


Figure 5

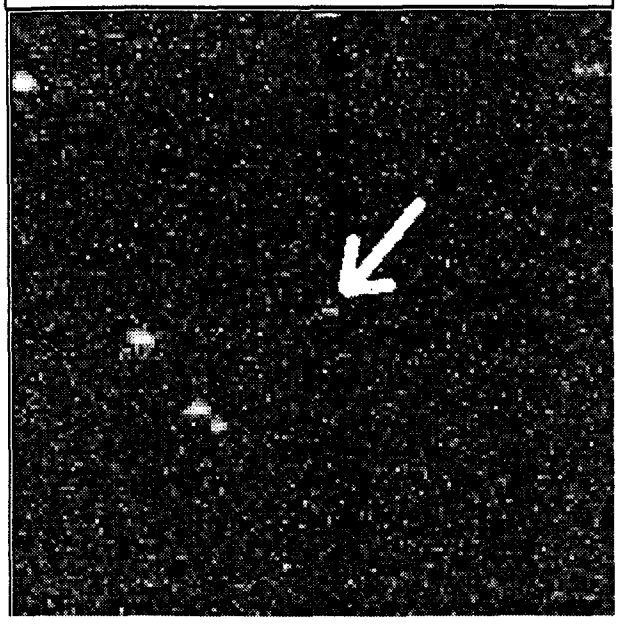


Figure 6

Figure 7

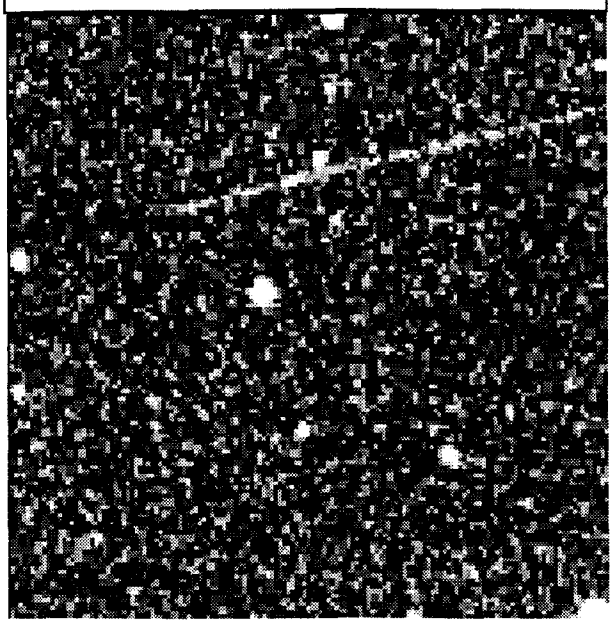


Figure 8

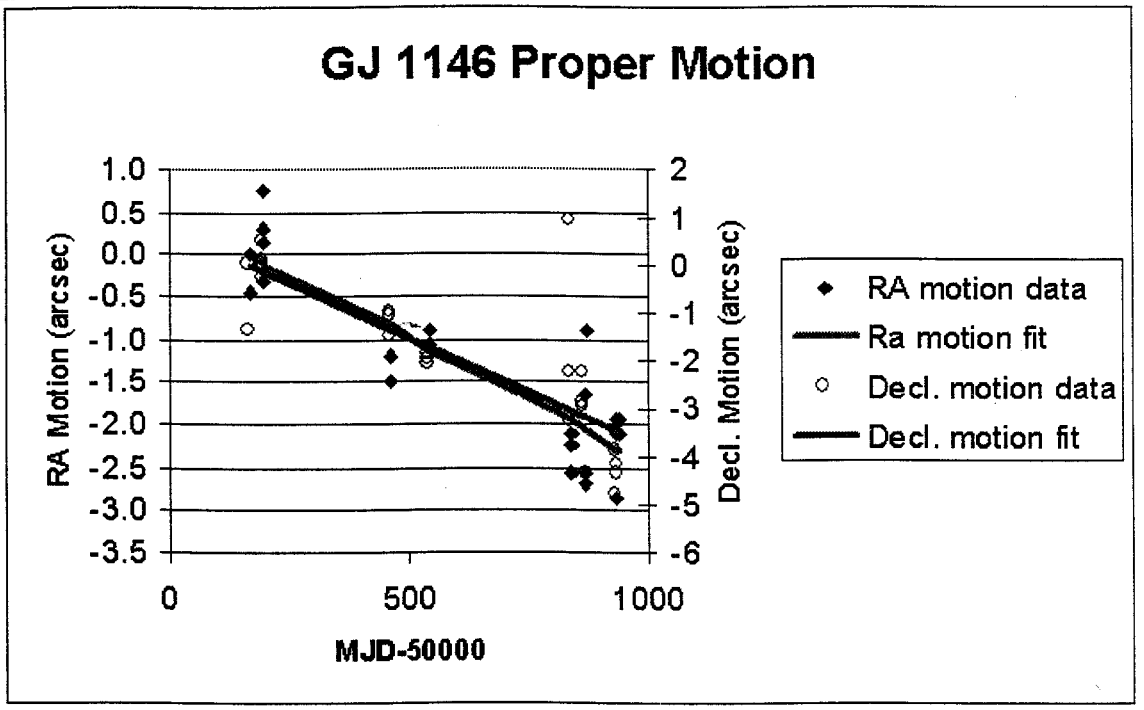

GJ 1146 Proper Motion
RA Motion (arcsec)
Decl. Motion (arcsec)
MJD-50000
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
2
1
0
-1
-2
-3
-4
-5
-6
0
500
1000
RA motion data
Ra motion fit
Decl. motion data
Decl. motion fit

Figure 9

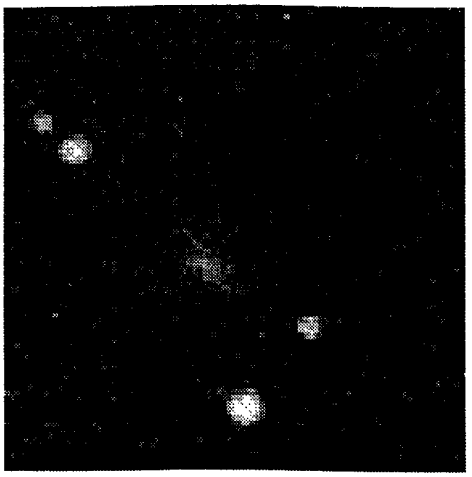


Figure 1a: 24 March 1998

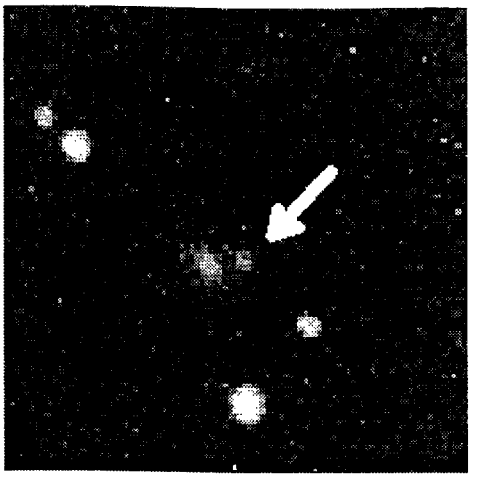
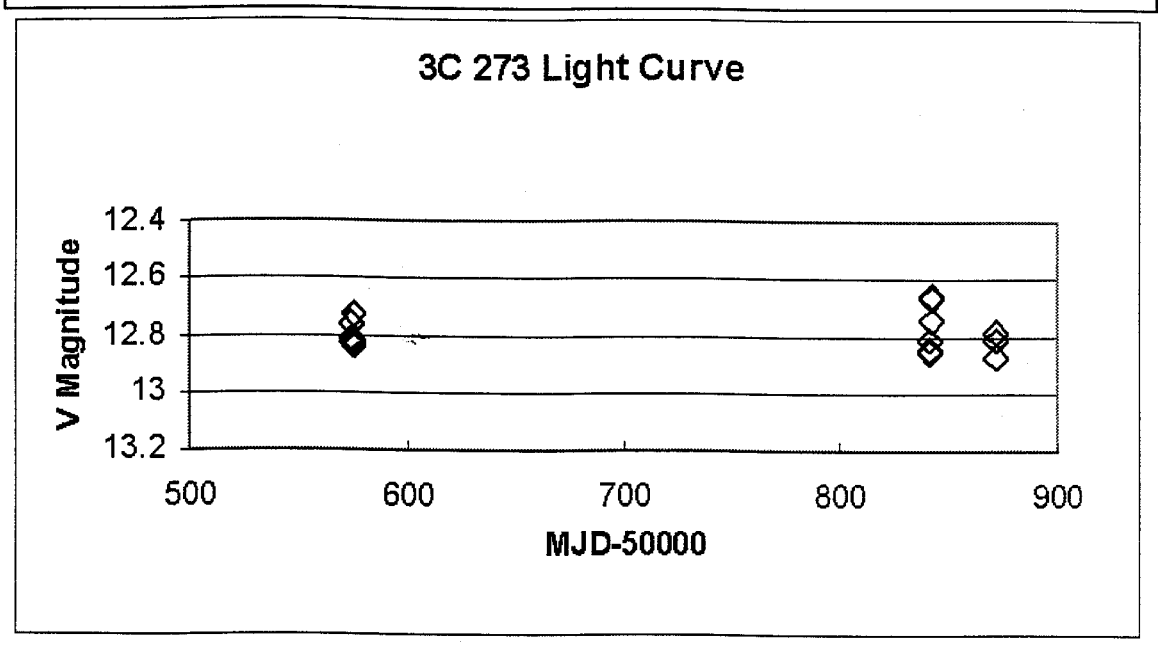


Figure 1b: 18 February 1999

Figure 10


3C 273 Light Curve
V Magnitude
12.4
12.6
12.8
13
13.2
500
600
700
800
900
MJD-50000